Copy 5
RM E52G07

NACA RM E52G07

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

NACA

RESEARCH MEMORANDUM

TEMPERATURE RESPONSE OF TURBINE-BLADE METAL COVERED WITH OXIDE COATINGS SUPPLIED BY FUEL ADDITIVES

By Richard J. McCafferty and Helmut F. Butze

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

CLASSIFICATION CANCELLED

Authority Naca Res. Abs. + Date 7-20-56
RN-104
By nb 8-6-56 See

CLASSIFIED DOCUMENT

This material contains information affecting the National Defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
August 20, 1952

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

TEMPERATURE RESPONSE OF TURBINE-BLADE METAL COVERED WITH OXIDE COATINGS SUPPLIED BY FUEL ADDITIVES

By Richard J. McCafferty and Helmut F. Butze

2641

SUMMARY

An investigation was conducted to determine the effects of turbine-blade coatings, supplied by fuel additives, on heat transfer from combustor exhaust gases to an S-816 alloy blade. Two fuel additives were used; tetraethyl orthosilicate (producing silicon dioxide) and triamyl borate (producing boric oxide). Data were obtained which described the blade-metal temperature response to exhaust-gas temperature for both static and transient gas temperature conditions in the range from 1400° to 2000° F.

The results showed that the fuel additives provided an oxide coating on the combustor-liner wall and the other metal parts, including the blade, exposed to the exhaust gas. The coating formed on the exterior surface of the blade had no measurable effect on blade-metal temperature at either static or transient exhaust-gas temperature conditions.

INTRODUCTION

Turbine-blade life is an important factor controlling operation and utilization of turbojet engines. High gas temperatures impose severe operating conditions on turbine blades and metal fracture often results. Cooler operating blades can provide longer blade life, decrease the consumption of strategic metals used in their manufacture, or allow increased gas temperatures. The NACA Lewis laboratory is conducting research on methods which may be used to reduce blade-metal operating temperatures. The use of air or water for cooling turbine blades internally is discussed in reference 1. The results of an analytical study of the use of ceramic coatings for reducing the metal temperature in the trailing edge of water-cooled blades are presented in reference 2. Although these results indicate that, for continuous operation, only small reductions in blade-metal temperature can be expected with certain ceramic-type coatings applied to low-conductivity metal alloys, the use of such coatings may allow higher gas temperatures and increased thrust for a short duration by increasing the time required for the blades to assume the new, higher gas temperature. The investigation reported herein was concerned specifically with this application.

A turbine blade was mounted in the exhaust ducting of a turbojet combustor rig. The coatings considered in this investigation were produced by additives contained in the fuel. Two additives were used; one producing a silicon dioxide coating and the other, a boric oxide coating. The temperature-response rates of coated and uncoated blades to rapid changes in exhaust-gas temperature were determined.

APPARATUS AND PROCEDURE

2641

An S-816 alloy turbine blade was mounted on a rod and inserted in the exhaust duct of a single combustor from a J33 turbojet engine. An attempt was made to mount the blade in the duct in such a manner as to simulate the gas-flow environment that exists in a full-scale engine. The detailed instrumentation and equipment features of the combustor setup are described in reference 3. Figure 1 shows the location of the blade with respect to the combustor and the thermocouple station used to measure the average exhaust-gas temperature. The local gas temperature at the blade was measured by two thermocouples located directly upstream of the blade. The blade-metal temperature was measured by a thermocouple inserted in the middle of the blade halfway between the root and the tip in the center of the chord. The blade-metal and the average exhaust-gas temperatures were continuously recorded on an oscillograph. Typical oscillograph traces are shown in reference 4 where turbojet-engine data variables were recorded.

The combustor was first operated to determine the inlet conditions that would allow a maximum exhaust-gas velocity around the blade at a gas temperature of 2000° F. The air conditions at the combustor inlet and at the blade are shown in table I. The inlet conditions were set and the combustor was operated at an average exhaust-gas temperature of 1400° F. Fuel-flow rate was then increased sufficiently in 9 to 13 seconds to raise the average exhaust-gas temperature to approximately 2000° F. This time interval is hereinafter referred to as "fuel-step time". When the fuel additives were used the combustor was operated at the 1400° F condition for a minimum of 1 hour in order to form an oxide film on the blade. The rates of change of exhaust-gas temperature with fuel addition and of blade-metal temperature with exhaust-gas temperature were recorded in separate tests because of the limitations of the recording system used.

Fuels

The base fuel used in this investigation was MIL-F-5624A, grade JP-4. Two fuel-additive mixtures were used, one containing 3 percent (by weight) tetraethyl orthosilicate and the other, 8 percent (by weight) triamyl borate. These concentrations correspond to 1 percent silicon dioxide and 1 percent boric oxide, respectively. The tetraethyl orthosilicate was commercially prepared; the triamyl borate was prepared at the Lewis laboratory by reacting amyl alcohol with anhydrous boric oxide.

RESULTS AND DISCUSSION

2641 Photographs of the turbine blade removed from the exhaust duct after operation with JP-4 fuel are shown in figures 2(a) and 2(b). Similar photographs of the blade after operation with JP-4 fuel plus additives are shown in figures 2(c) to 2(f). Noticeable coatings were formed during the 1.4- and the 1.6-hour running times. The triamyl borate provided a less uniform, but thicker, more stable coating than did the tetraethyl orthosilicate. The silicon dioxide coating was dry and powdery and was easily removed when touched.

Photographs of the combustor liner and the deposits formed are presented in figure 3. The deposits were stable with respect to the action of heat and air wash produced by operation with clear JP-4 fuel; these photographs were taken after the liner had been operated an additional 1/2 hour without any fuel additive being present.

The data obtained with the JP-4 fuel and two additives are summarized in table I, and the turbine blade-temperature against time relations obtained for several runs with clear JP-4 fuel and with each additive are presented in figure 4. The dotted lines are representative curves of the average combustor exhaust-gas temperature during the fuel input change for each fuel. The perpendicular lines located on each curve indicate the fuel-step time for that particular run. In figure 5, the blade-temperature curves obtained with JP-4 fuel and with JP-4 fuel plus additives are compared. The fuel additive coating had little or no effect on blade-metal temperature response since the slopes of the curves in figure 5 are all very similar. The characteristic time factor (defined as the length of time required for the blade to increase 63 percent of the total temperature change) for each run is also shown in figure 5. The characteristic time factors were approximately the same whether the blade was coated or uncoated; again, little effect of the coating on the rate of heat transfer to the blade is indicated.

The spread among the curves is due to the slightly different fuel-step times and to the differences in temperature of the blade before the fuel-flow change. Although the average exhaust-gas temperature was nearly identical for all runs, the temperature distribution across the combustor duct was different with each fuel used. A comparison, at the initial conditions, of the average gas temperatures and the local gas temperatures near the blade indicates an average gas temperature variation of 50° F and a local gas temperature variation of 340° F for all runs (see table I). Thus, the initial temperature of the blade was altered by variation in the local gas temperature and not by the coating, which, in some cases, caused the blade-metal temperature to be higher than the average gas temperature at the initial conditions (see fig. 4(b)).

Curves which resulted from almost identical fuel-step times are presented in figure 6. The initial blade temperatures for these runs were as close to each other as could be selected from the data. No difference in blade-metal temperature response was noted with the fuel additives.

2641

A slight decrease in combustion efficiency was observed when the additives were present in the fuel. The average combustion efficiency (table I) at both initial and final fuel-step conditions with JP-4 fuel was 97 percent; with JP-4 fuel plus tetraethyl orthosilicate, 95 percent; and with JP-4 fuel plus triamyl borate, 95 percent. However, the combustor-inlet-air pressure and temperature were very favorable to combustion, and high efficiency values, with small differences among fuels, could be predicted.

The normal operating axial gas velocity range for turbojet engines is from 800 to 1200 feet per second at the turbine blade position (reference 5). Because of test-setup limitations, the data presented herein were obtained at gas-flow velocities at the blade of approximately 370 to 510 feet per second; a flat velocity profile and a nominal combustor pressure drop were assumed.

It was assumed that trends observed at these lower velocities would be similar to those obtained at higher velocities. Therefore, the negative results of the present investigation may be considered to apply to full-scale engine conditions if the quantity of heat transferred from the blade to the turbine disk is negligible for the short durations considered.

SUMMARY OF RESULTS

The following results were obtained in an investigation of the temperature-response characteristics of an S-816 alloy turbine blade covered with silicon dioxide and boric oxide coatings supplied by fuel additives:

1. Tetraethyl orthosilicate and triamyl borate additives in JP-4 fuel provided a stable oxide coating on combustor-liner walls and on other metal parts exposed to the exhaust-gas stream.

2. The protective coating formed had no measurable effect on turbine-blade-metal temperature ~~at various~~ combustor exhaust-gas temperatures, or on rates of blade-metal temperature response to rapid changes in exhaust-gas temperature.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 17, 1952

2641

REFERENCES

1. Ellerbrock, Herman H. Jr., and Schafer, Louis J. Jr.: Application of Blade Cooling to Gas Turbines. NACA RM E50A04, 1950.

2. Brown, W. Byron, and Livingood, John N. B.: Cooling of Gas Turbines. IX - Cooling Effects from Use of Ceramic Coatings on Water-Cooled Turbine Blades. NACA RM E8H03, 1948.

3. Wear, Jerrold D., and Douglass, Howard W.: Carbon Deposition from AN-F-58 Fuels in a J33 Single Combustor. NACA RM E9D06, 1949.

4. Delio, Gene J., and Schwent, Glennon V.: Instrumentation for Recording Transient Performance of Gas-Turbine Engines and Control Systems. NACA RM E51D27, 1951.

5. Vincent, E. T.: The Theory and Design of Gas Turbines and Jet Engines. McGraw-Hill Book Co., Inc., 1st ed., 1950.

SECURITY INFORMATION
CONFIDENTIAL

TABLE I - DATA FOR TEMPERATURE-RESPONSE INVESTIGATION OF TURBINE-BLADE METAL COVERED WITH OXIDE COATINGS SUPPLIED BY FUEL ADDITIVES

Run	Air flow (lb/sec)	Combustor-inlet temperature (°F)	Combustor-inlet total pressure (in. Hg abs)		Fuel flow (lb/hr)		Fuel-air ratio		Fuel-step time (sec)	Average exhaust-gas temperature (°F)		Exhaust-gas temperature at blade (°F)		Blade-metal temperature (°F)		Temperature rise in blade (°F)	Characteristic time factor[a] (sec)	Combustion efficiency (percent)	
			Initial	Final	Initial	Final	Initial	Final		Initial	Final	Initial	Final	Initial	Final			Initial	Final
MIL-F-5624A (Grade JP-4) fuel																			
1	2.62	235	46.0	51.4	163	262	0.0173	0.0278	10.0	1400	2000	1535	2000	1425	1800	375	----	97.2	97.1
2	2.61	235	46.0	51.3	163	262	.0173	.0279	12.3	1400	2015	1340	2010	1450	1890	460	22.5	97.2	97.5
3	2.61	235	46.0	51.5	162	262	.0172	.0279	12.7	1400	2015	1370	2030	1455	1900	445	20.5	97.6	97.6
8	2.60	234	46.0	51.0	163	263	.0174	.0281	8.8	1390	1960	1255	1895	1440	1825	385	----	95.6	95.0
9	2.60	234	46.0	51.2	163	263	.0174	.0281	9.8	1390	2000	1280	1920	1445	1920	475	21.0	95.8	96.2
MIL-F-5624A (Grade JP-4) plus 3 percent tetraethyl orthosilicate (by weight)																			
4	2.62	232	46.0	51.3	163	262	0.0173	0.0278	12.5	1385	1950	1490	2100	1495	1890	395	24.5	95.4	95.4
5	2.61	235	46.0	51.9	163	263	.0173	.0280	11.4	1370	1950	1580	2135	1525	1950	425	23.5	95.6	94.7
6	2.61	235	46.0	52.0	164	266	.0174	.0285	14.3	1370	1960	1585	2145	1525	1930	405	----	95.1	94.4
7	2.62	233	46.0	51.9	163	262	.0173	.0279	8.7	1350	1925	1485	2100	1495	1930	435	26.0	93.8	93.4
MIL-F-5624A (Grade JP-4) plus 8 percent triamyl borate (by weight)																			
10	2.60	236	46.0	50.8	163	262	0.0174	0.0280	9.3	1380	1960	1540	2010	1430	1900	470	----	96.0	95.2
11	2.60	236	46.0	50.9	163	262	.0174	.0280	12.0	1380	1965	1350	1995	1420	1900	480	21.0	96.0	95.5
12	2.60	236	46.0	50.6	163	262	.0174	.0280	12.5	1380	1950	1250	1950	1385	1860	475	----	96.0	94.6
13	2.60	236	46.0	50.8	163	265	.0174	.0281	13.4	1385	1960	1245	1980	1375	1875	500	21.0	95.4	94.9

[a]Time required for blade temperature to increase 63 percent of total temperature rise.

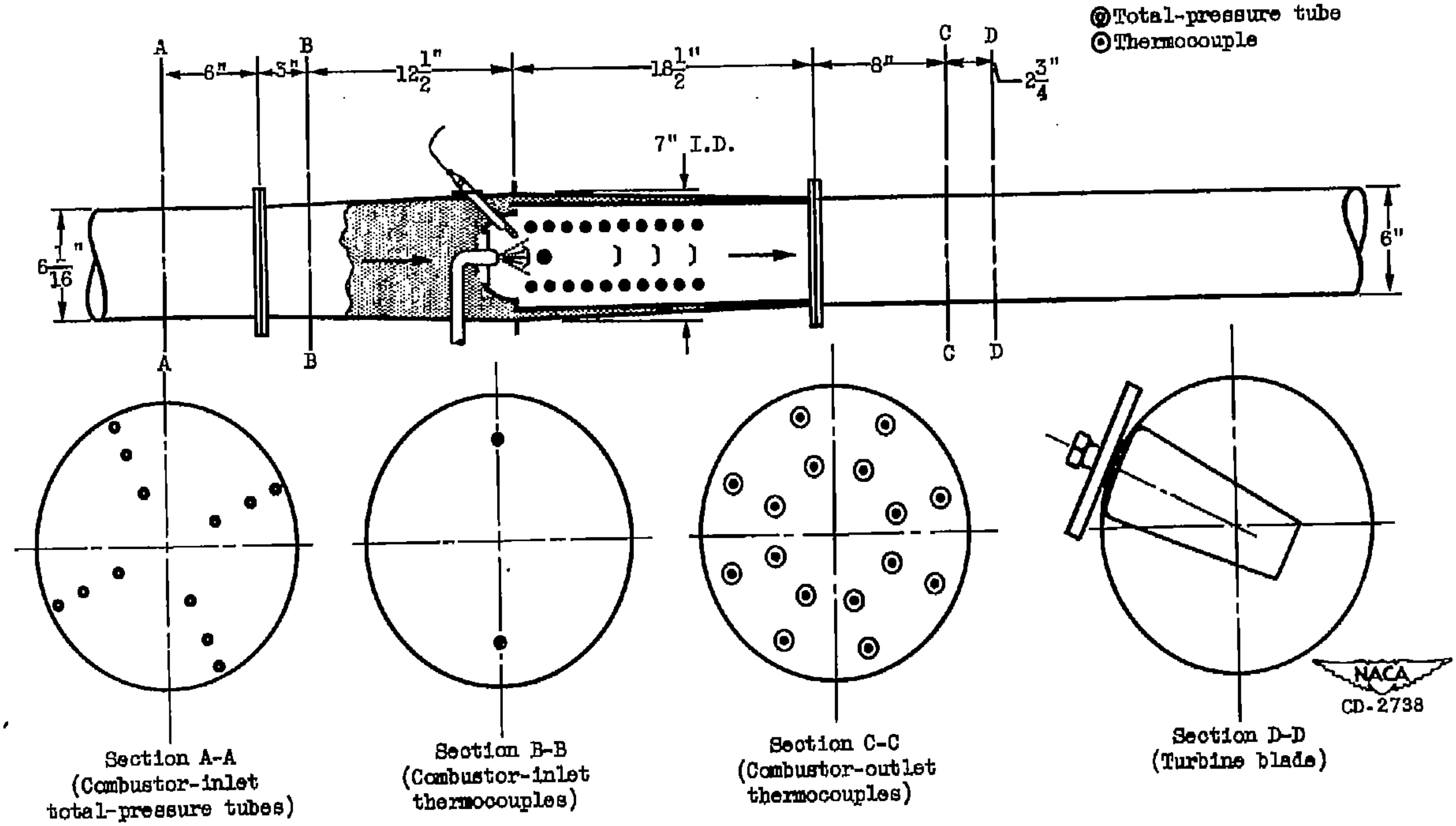
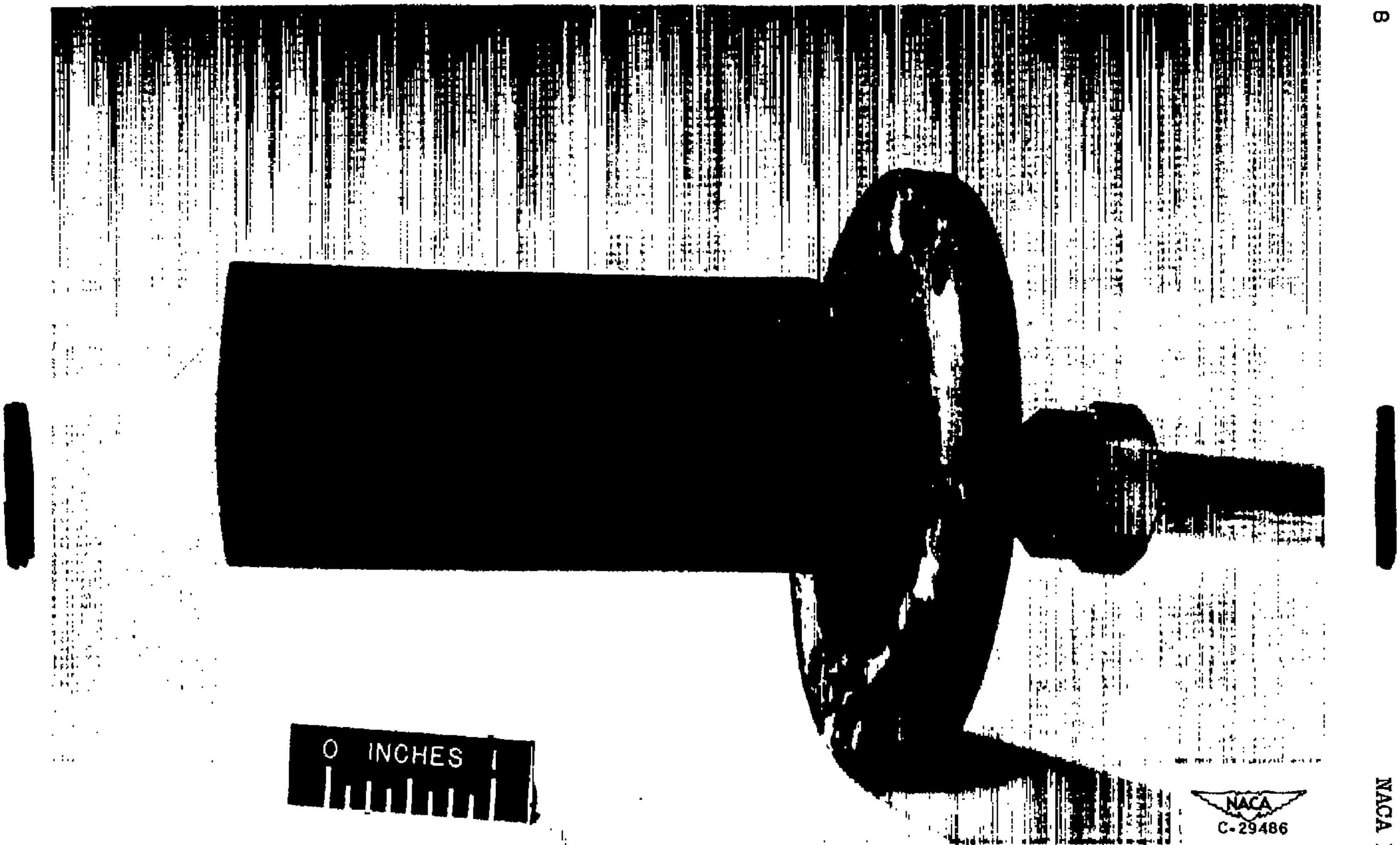
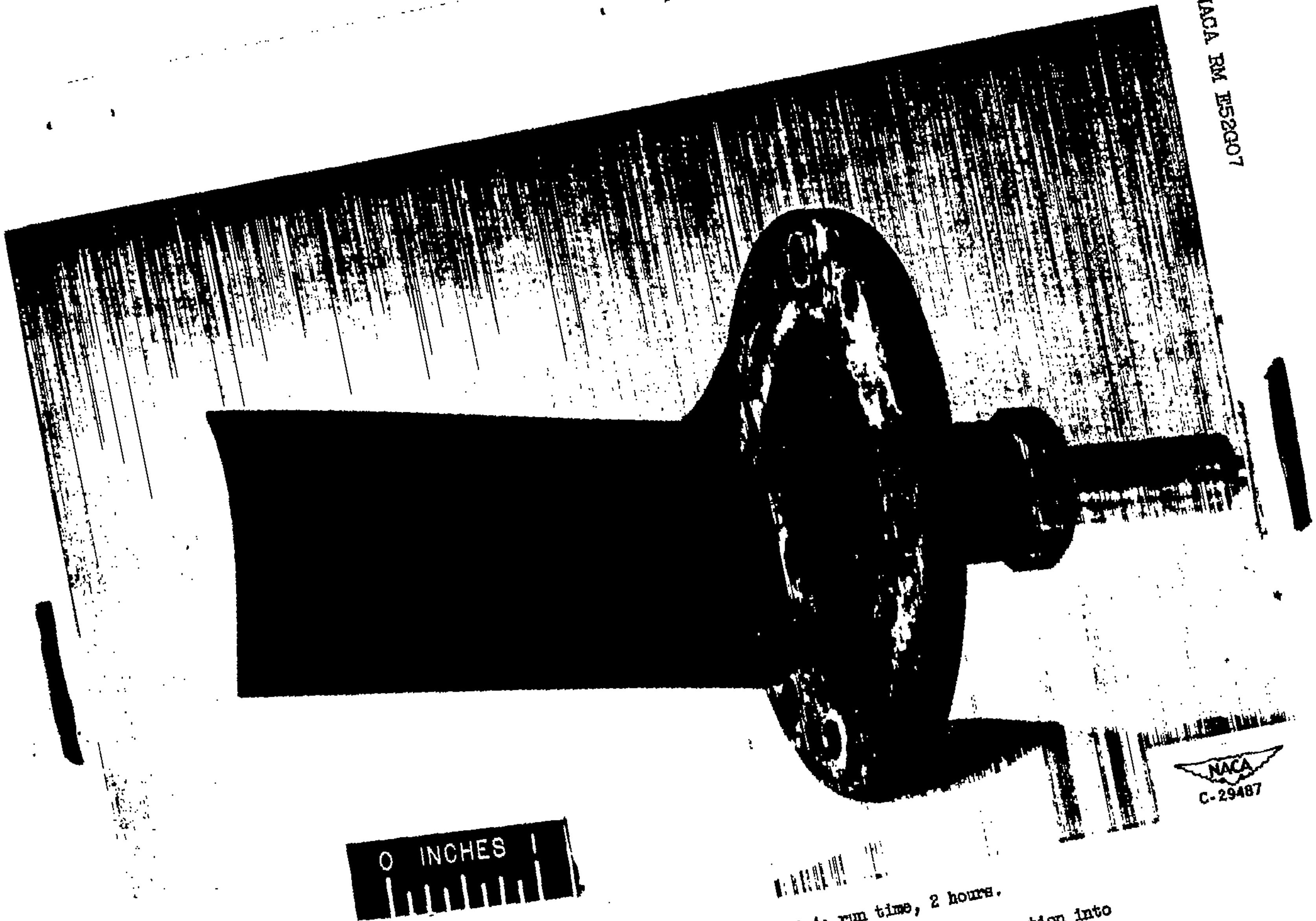


Figure 1. - Single-combustor installation showing ducting, location of temperature- and pressure-measuring instruments, and turbine blade.



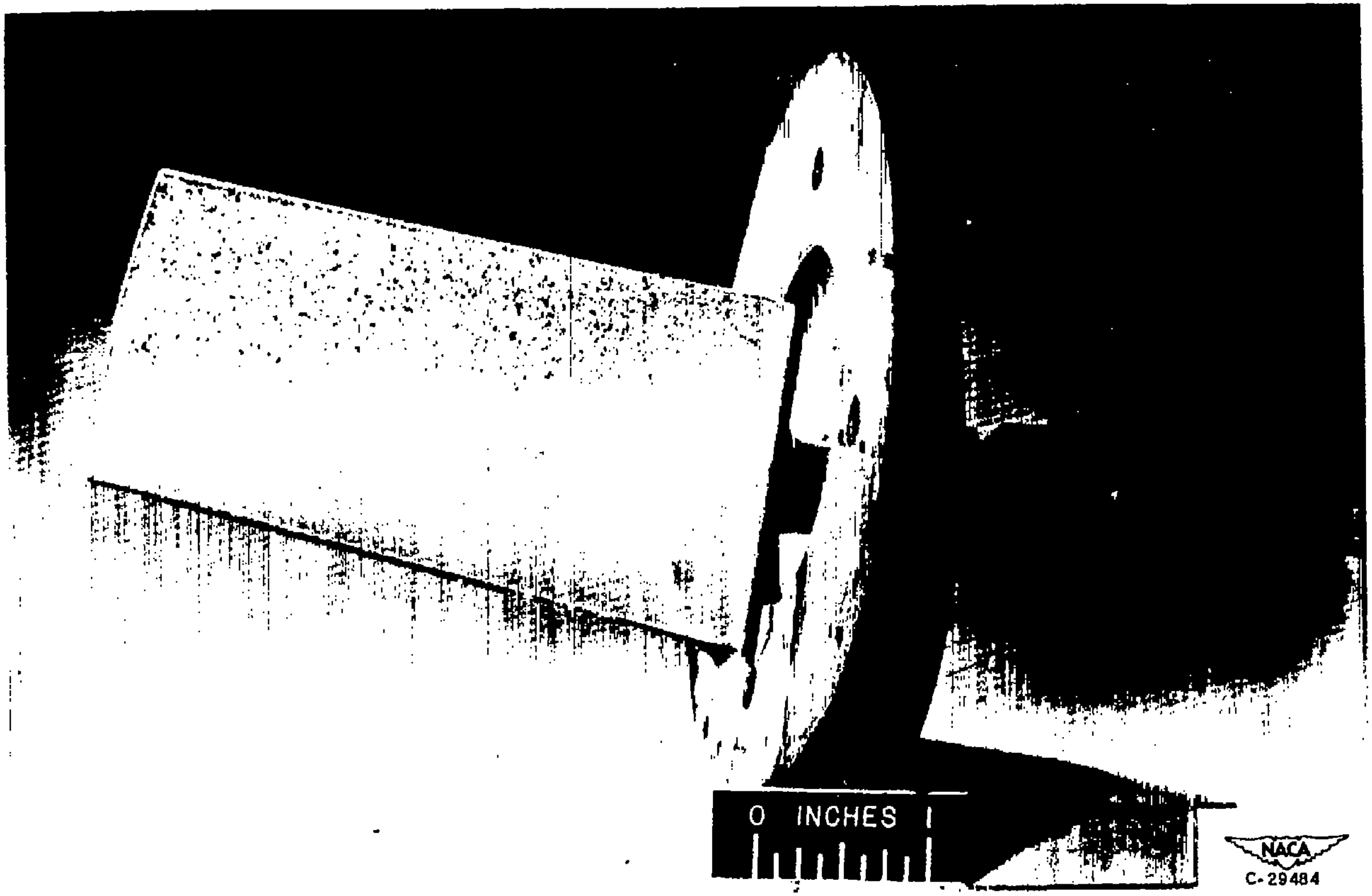
(a) Driving face of blade. Fuel, JP-4; run time, 2 hours.

Figure 2. - Photograph of S-816 alloy turbine blade after insertion into exhaust-gas stream of single combustor operating with JP-4 fuel and JP-4 fuel plus additives.



(b) Trailing face of blade. Fuel, JP-4; run time, 2 hours.

Figure 2. - Continued. Photograph of S-816 alloy turbine blade after insertion into exhaust-gas stream of single combustor operating with JP-4 fuel and JP-4 fuel plus additives.



(c) Driving face of blade. Fuel, JP-4 plus tetraethyl orthosilicate; run time, 1.4 hours.

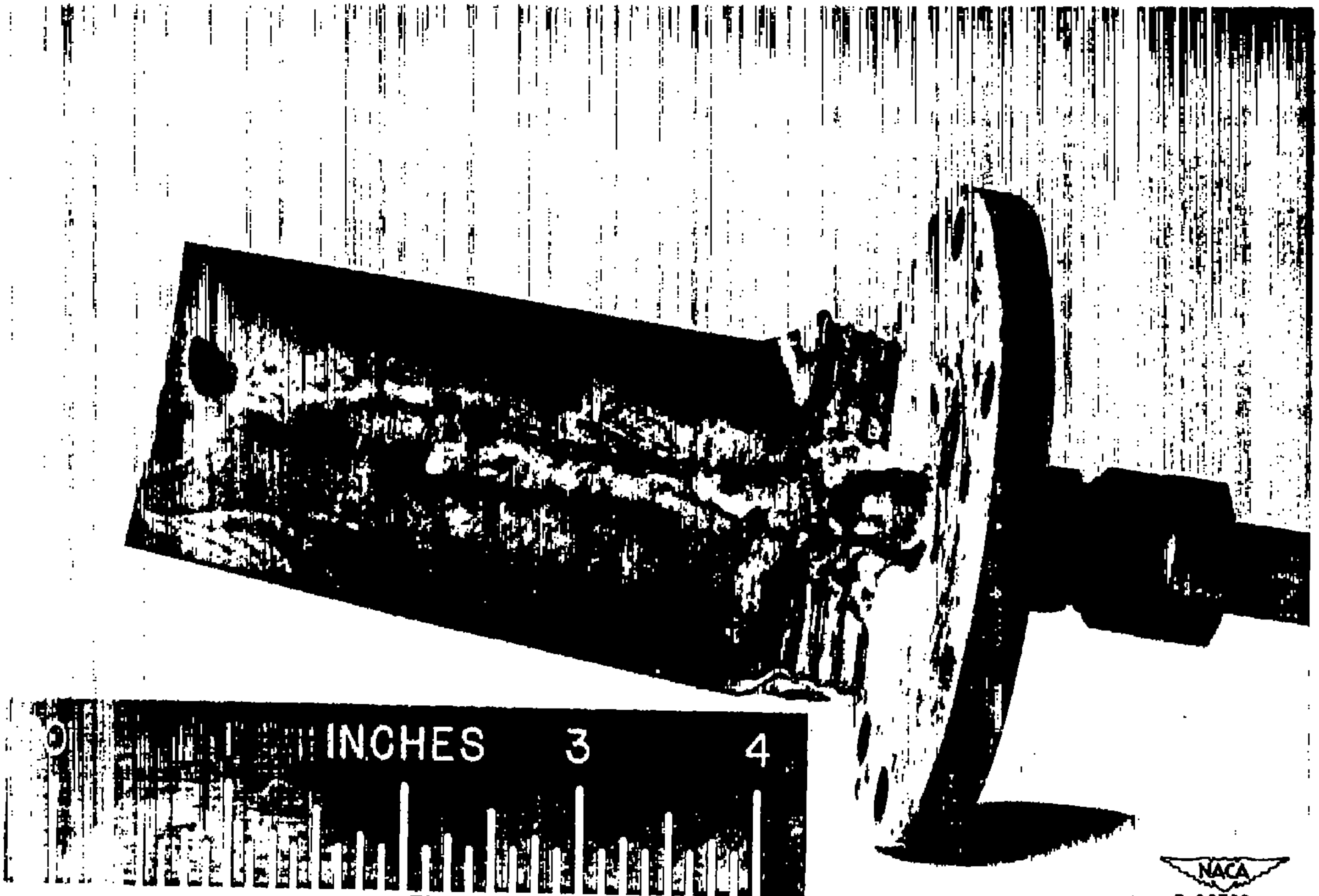
Figure 2. - Continued. Photograph of S-816 alloy turbine blade after insertion into exhaust-gas stream of single combustor operating with JP-4 fuel and JP-4 fuel plus additives.

(d) Trailing face of blade. Fuel, JP-4 plus tetraethyl orthosilicate; run time, 1.4 hours.

Figure 2. - Continued. Photograph of S-816 alloy turbine blade after insertion into exhaust-gas stream of single combustor operating with JP-4 fuel and JP-4 fuel plus additives.

(e) Driving face of blade. Fuel, JP-4 plus triamyl borate; run time, 1.6 hours.

Figure 2. - Continued. Photograph of S-816 alloy turbine blade after insertion into exhaust-gas stream of single combustor operating with JP-4 fuel and JP-4 fuel plus additives.

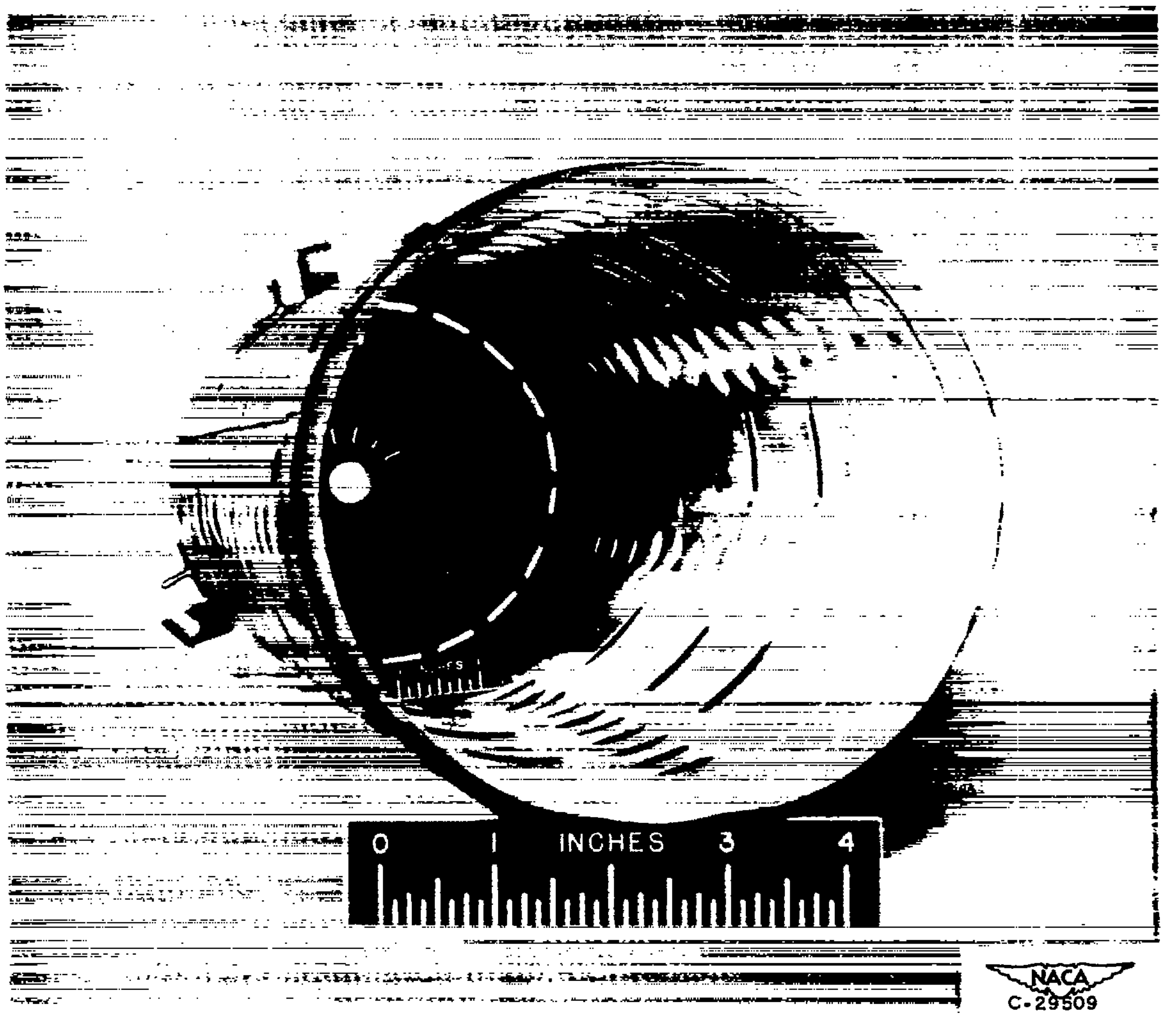


C-29726

(f) Trailing face of blade. Fuel, JP-4 plus triamyl borate; run time, 1.6 hours.

Figure 2. - Concluded. Photograph of S-816 alloy turbine blade after insertion into exhaust-gas stream of single combustor operating with JP-4 fuel and JP-4 fuel plus additives.

2641



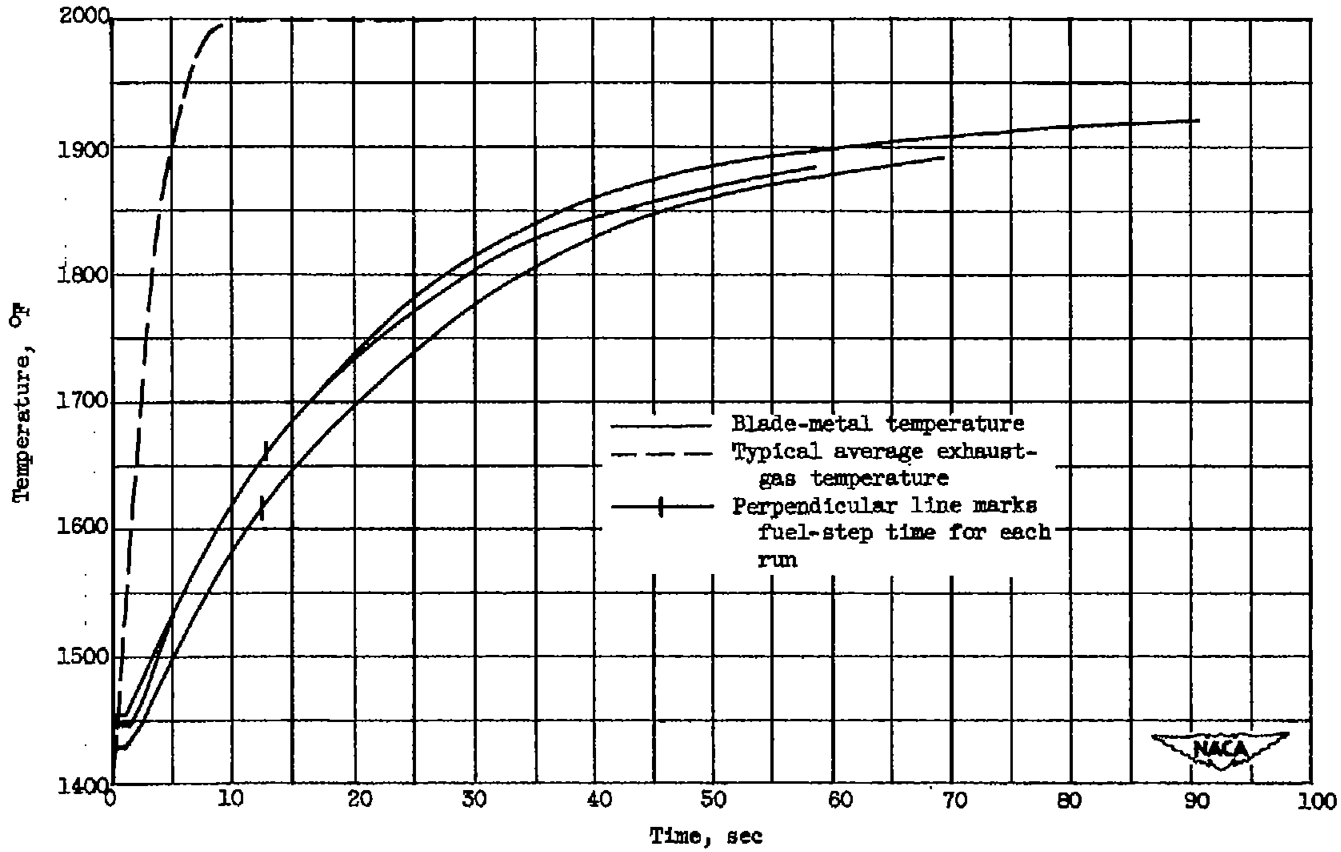
(a) Fuel, JP-4 plus tetraethyl orthosilicate; run time, 1.4 hours with JP-4 fuel plus additive and 0.5 hour with JP-4 fuel.

Figure 3. - Photograph of J33 combustor liner after operation with JP-4 fuel and JP-4 fuel plus additives.

2641

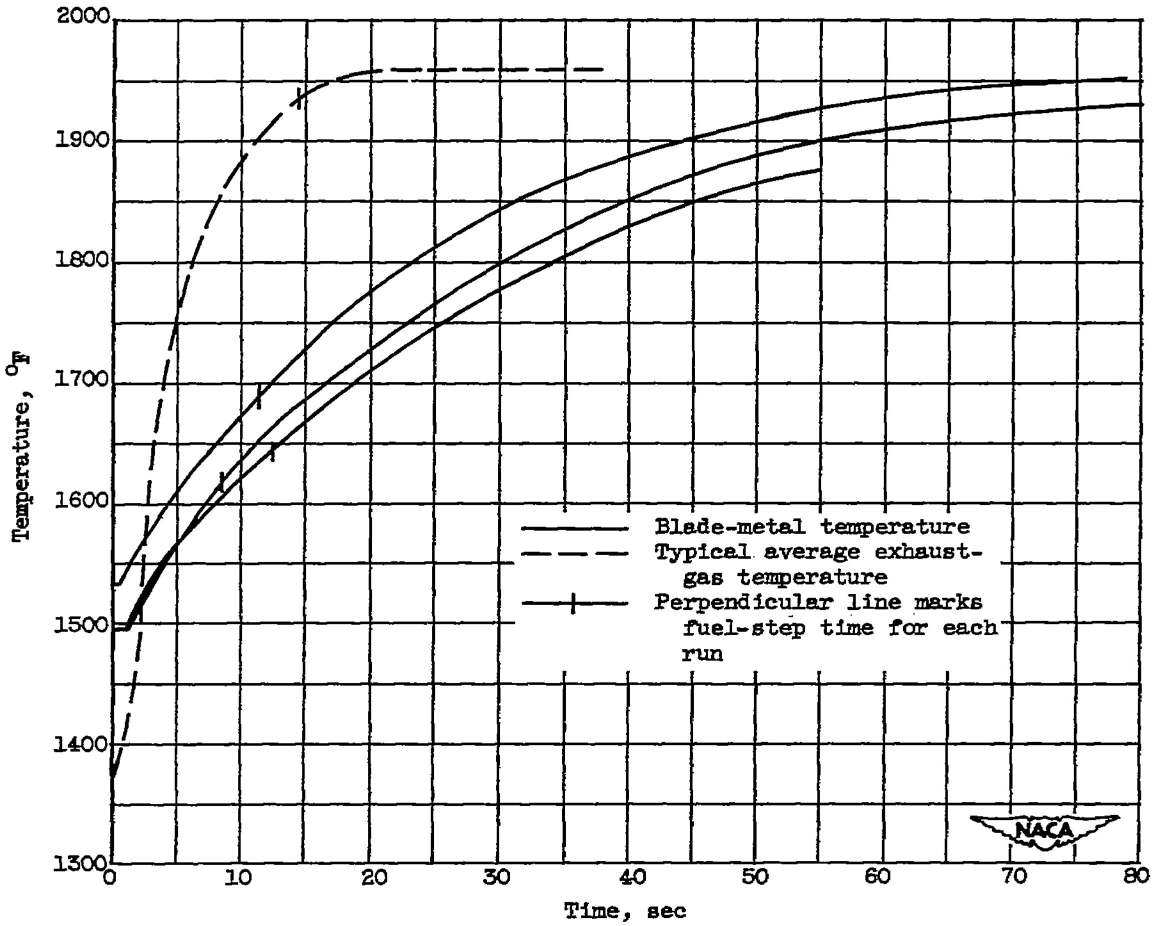
(b) Fuel, JP-4 plus triamyl borate; run time, 1.6 hours with JP-4 fuel plus additive and 0.5 hour with JP-4 fuel.

Figure 3. - Concluded. Photograph of J33 combustor liner after operation with JP-4 fuel and JP-4 fuel plus additives.



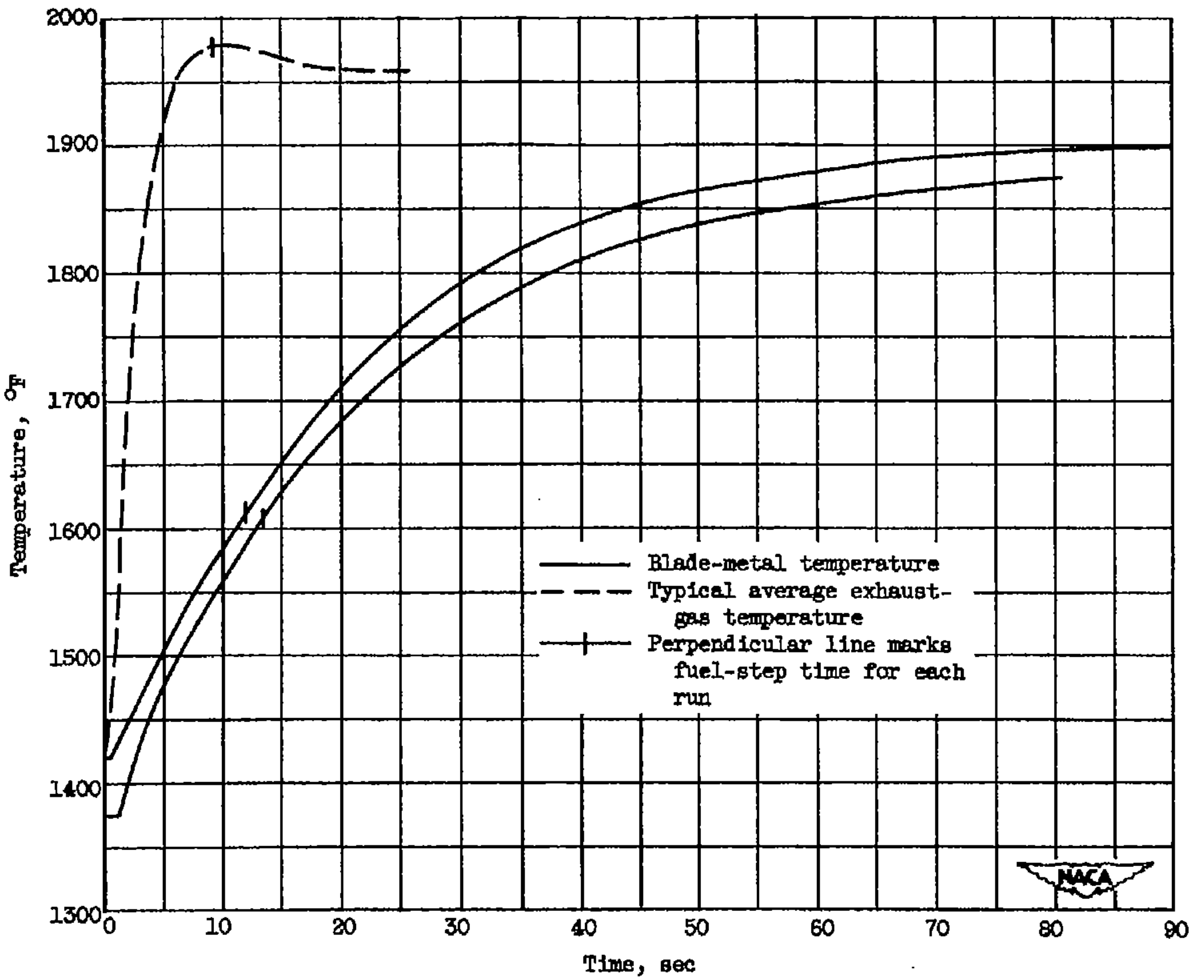
(a) Fuel, JP-4.

Figure 4. - Turbine-blade-metal and average exhaust-gas temperatures against time for several fuel steps with JP-4 fuel and JP-4 fuel plus additives. Blade alloy, S-816.



(b) Fuel, JP-4 plus tetraethyl orthosilicate.

Figure 4. - Continued. Turbine-blade-metal and average exhaust-gas temperatures against time for several fuel steps with JP-4 fuel and JP-4 fuel plus additives. Blade alloy, S-816.



(c) Fuel, JP-4 plus triamyl borate.

Figure 4. - Concluded. Turbine-blade-metal and average exhaust-gas temperatures against time for several fuel steps with JP-4 fuel and JP-4 fuel plus additives. Blade alloy, S-816.

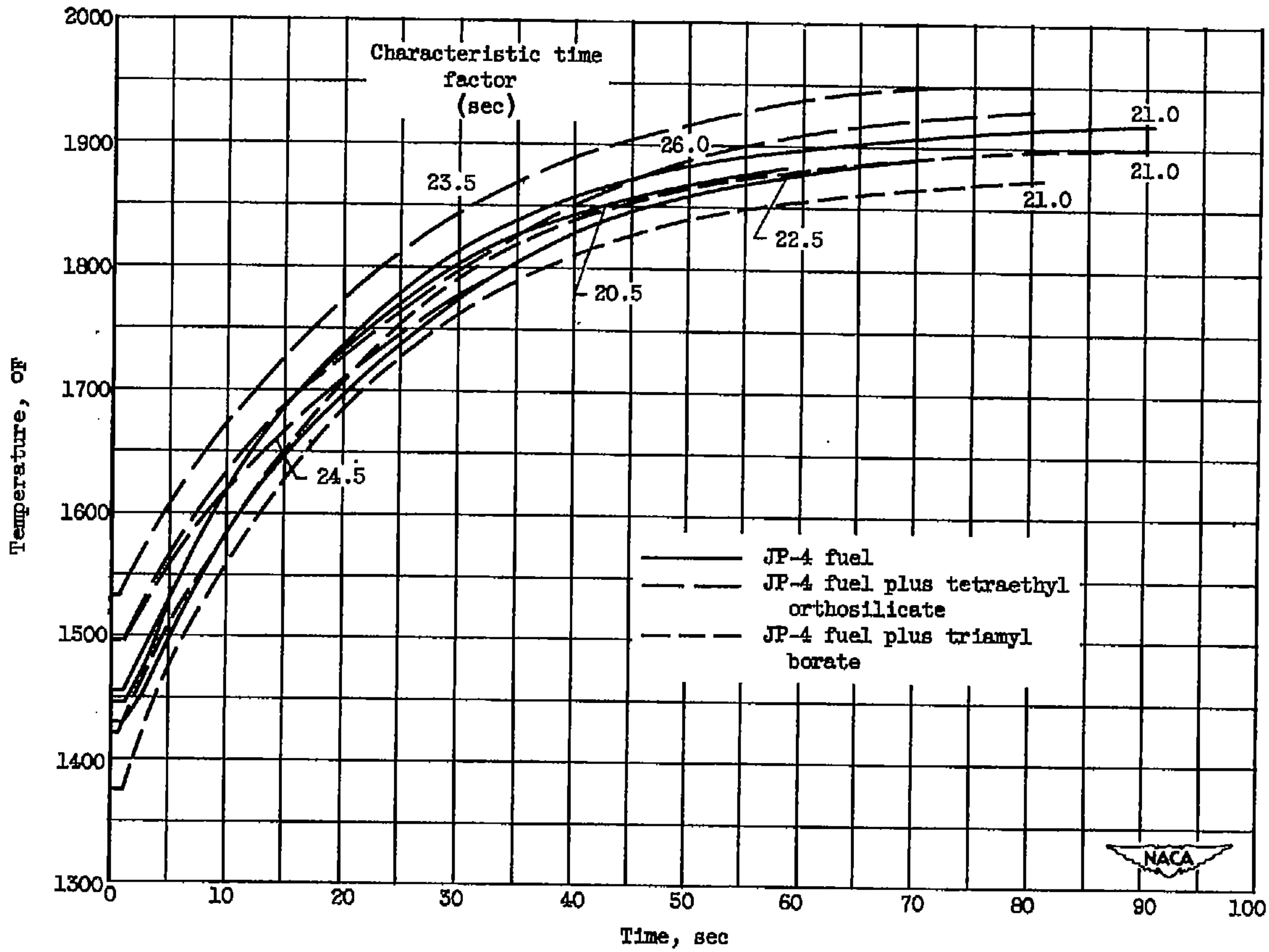


Figure 5. - Comparison of response rates of turbine-blade-metal temperature to fuel steps with JP-4 fuel and JP-4 fuel plus additives. Blade alloy, S-816. Exhaust-gas temperature: initial, approximately 1400° F; final, approximately 2000° F.

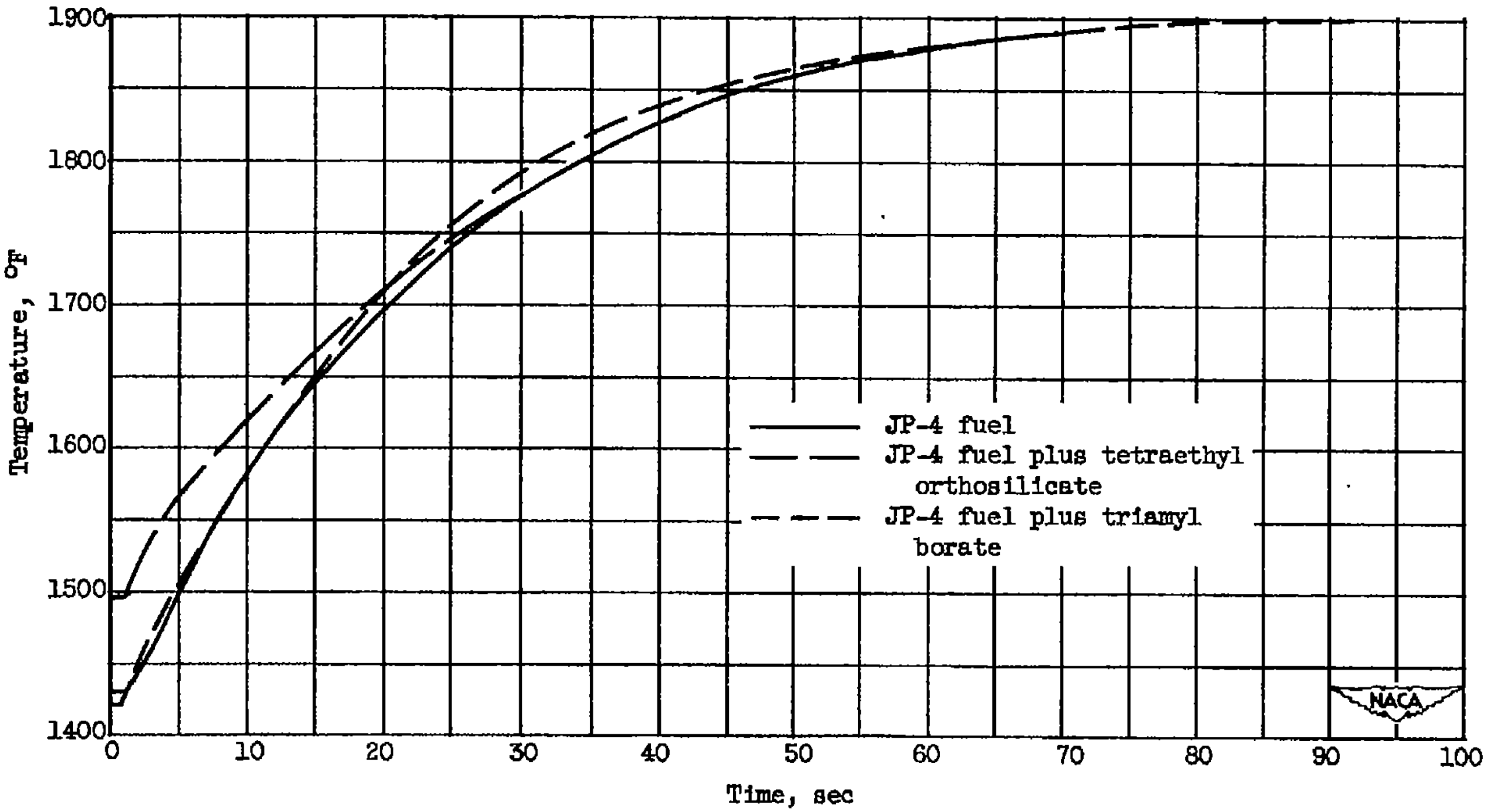


Figure 6. - Turbine-blade-metal temperature against time for same fuel-step-time values with JP-4 fuel and JP-4 fuel plus additives. Blade alloy, S-816. Exhaust-gas temperature; initial, approximately 1400° F; final, approximately, 2000° F.

NACA-Langley - 8-20-52 - 500

[redacted]

[redacted]